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(54) IMPROVEMENTS IN SOUND-REDUCING HOUSING FOR ALTERNATING CURRENT ELECTRIC APPARATUS

(71) We, GENERAL ELECTRIC COMPANY, a corporation organized and existing under the laws of the State of New York, United States of America, residing at 1 River Road, Schenectady 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to sound-reducing means for alternating current electric apparatus such as electric induction apparatus, and more particularly to sound reducing housing structures of the ventilated type for air-cooled apparatus.

Power transformers which range in rating up to about 10,000 kva at operating voltages up to about 15 kv are frequently of the ventilated dry-type in order to render the equipment both fireproof and explosion proof. Because the housings for such transformers contain air, as distinct from a liquid, as an insulating fluid and coolant, they can be operated at relatively high temperatures. While their operating voltages are limited as a practical matter to about 15 kv, such transformers increasingly constitute an important class of apparatus finding widespread application inside residential and commercial buildings where ambient noise from other sources is at very low levels.

In ventilated dry-type transformers, the basic function of transforming voltage is performed by the usual core and coil assembly. In operation this assembly vibrates as a result of alternating current through the coils and emits sound comprised primarily of frequencies which are even harmonics of the frequency of the applied voltage. For example, an applied voltage having a frequency of 60 cycles per second (cps) would result in sound frequencies of 120, 240, 360 cps etc., with the lower frequencies predominating in amplitude. Such transformers are usually provided with an enclosing housing of sheet metal to protect the high voltage portions of the core and coil assembly. To provide for forced or natural circulation of cooling air, such a housing ordinarily has one opening near the bottom and at least one opening near the top. The housing provides inherently for some sound attenuation due to containment of the core and coil. However this containment principle, while normally resulting in a reduction in sound level outside the housing, actually increases the sound level near the vicinity of the core and coil assembly because of reflection of sound energy within the housing. Therefore the sound-containment effect is generally supplemented by sound-absorbing or attenuating means interposed in the air path between the core and housing and by providing vibration isolating supporting means between the housing base and the core and coil assembly. Vibration isolation is usually in the form of resilient mounts for the core and coil and flexible connections to housing mounted bushings. For attenuation of reflected sound in the air space between the core and housing, glass fibre-lining or panels may be used to reduce the internal build-up of sound by reflection. These sound-reduction techniques afford some improvement in external sound levels, but they are of limited effectiveness due to the relatively large inlet and outlet openings required for passage of cooling air. These openings are usually so large, especially on apparatus cooled by natural circulation of air, that the direct transmission of sound therethrough is in itself objectionable.

According to the present invention there is provided an air-cooled electric apparatus of the alternating current type enclosed in a ventilated housing which is provided with a cooling air inlet opening and a cooling air outlet opening for the passage of air through the housing to cool said apparatus, wherein adjacent at least one of said openings is mounted a chambered air duct structure comprising a tubular air pasageway and at least one resonating chamber, one wall of the or

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each chamber being constituted by a wall of said passageway, said passageway wall extending across substantially the full width of said air passageway, and the or each chamber communicating with said passageway by means of a tubular orifice passing through said wall, the or each orifice and its associated chamber constituting an acoustic resonator tuned to a selected frequency of the sound generated by said apparatus in operation, whereby to attenuate said sound.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:—

Fig. 1 is a front elevational view of a transformer housing including sound-reducing features embodying the invention, the transformer itself and certain internal housing elements being shown in phantom display by broken lines;

Fig. 2 is a vertical cross-sectional view of the transformer apparatus of Fig. 1 taken along the line A—A of Fig. 1;

Fig. 3 is a perspective view of an integral air duct and resonating chamber assembly included in the transformer housing shown at Figs. 1 and 2; and

Fig. 4 is a graphical representation of certain test results illustrating the relative degrees of attenuation of sound at various frequencies resulting from its passage through a resonant chambered duct such as that of Fig. 3.

Referring now to Figs. 1 and 2, there is shown a ventilated dry-type transformer apparatus comprising a rectangular box-like housing 1 preferably formed of sheet metal and mounted directly upon a supporting pad or base 2. The base 2 may suitably be a rigid concrete foundation pad of relatively massive proportion. The front wall of the housing, as shown at Fig. 1, is provided at its lower end with a large cooling air inlet aperture 3 extending across substantially the entire width of the housing, and the upper end of the opposite or rear wall is provided with a similar cooling air outlet aperture 4 (shown at Fig. 1 in broken lines).

Within the housing 1 there is positioned a transformer core and coil assembly mounted upon the base or foundation 2 substantially in vibration-isolating independence of the housing 1. The transformer core illustrated comprises upper and lower yoke members 5 and 6, respectively, and three core legs 7, 8 and 9 extending in parallel spaced relation between the upper and lower yokes. Current-carrying coils or windings 10, 11 and 12 are positioned respectively on the core legs 7, 8 and 9. The upper yoke is provided with a pair of lifting brackets 14, 15 to which there may be connected suitable eye bolts (not shown) extending through the housing cover. The transformer core and coil assembly is mounted at an appreciable distance above the base 2 and upon two pairs of downwardly diverging supporting legs 20 and 21 fixed to opposite ends of the horizontal lower core yoke 6. Between the pairs of supporting legs 20, 21 and the base 2 there are interposed known resilient bearing members 22, 23.

Appreciable space is usually available beneath the core and between the pairs of supporting legs 20, 21, and it is into this space that the air inlet aperture 3 opens. The side walls of the housing 1 are also spaced an appreciable distance from the sides of the core and coil assembly in order to provide adequate circulation of air upwardly and around the sides of the core and coils. Similarly, ventilation and mechanical requirements direct that an appreciable space be provided between the top of the housing and the upper core yoke 5, and the air outlet opening 4 is adjacent this upper air space.

To attentuate sound transmitted within the housing in the manner described, the inner walls of the housing are lined throughout substantially the entire inner surface with sheets 25 of sound absorbing material, preferably glass fibre or the like. As shown in Fig. 2, glass fibre sheets 25 are mounted in slightly spaced relation with respect to the inner walls of the housing, as on supporting studs 26. It will be understood by those skilled in the art that it is not essential that the glass fibre sheets 25 be positioned against or immediately adjacent housing walls. They may, for example, be freely suspended at any point between the housing and the noise-generating source, i.e. the core and coil assembly.

The amount of air required for cooling, especially by natural circulation, is such that the air flow openings 3 and 4 in the lower and upper portions of the housing, respectively, are of considerable size. By natural circulation, air enters at the lower portion of the housing through the apertures 3 and is exhausted from the upper portion of the housing through the aperture 4, the path of circulation of the air upward through the housing being illustrated in broken lines at Fig. 2. The air flow openings 3 and 4 are necessarily of such area that unless some attenuating means is provided, appreciable sound would be transmitted directly through these openings from the interior to the exterior of the housing. The vibration isolating mounting of the core and coil assembly and the sound-absorbing lining of the casing, while effective for the purposes intended, do not in themselves have any effect upon the direct transmission of sound through the air flow apertures.

Transmission of sound through the air inlet and outlet openings of the ventilated apparatus housing 1 is substantially blocked by frequency-responsive air duct structures including resonant cavities. Such cavities are

tuned to attenuate selected sound frequencies which predominate in the noise generated by electric apparatus of the alternating current type. For this purpose there is mounted adjacent each air flow opening 3 and 4 an inwardly-extending unitary assembly of a tubular air passageway and one or more adjacent resonant chambers or cavities, each cavity being in communication with the duct through orifices of predetermined critical dimension in a wall common to the passageway and cavities. Such an integral chambered duct assembly is shown at Fig. 3.

The chambered air duct assembly comprises a plurality of box-like resonating chambers or cavities 29 and 30 having a common top wall 31 and a common bottom wall 32 apertured to provide a separate entrance orifice into each chamber. In Fig. 3, we have shown two chambers 29 of equal dimension and two chambers 30 of equal dimension but different in size from the chambers 29. Opposite side wall portions 33, 34 of the assembly extend beyond the chambers 29 and 30 in parallel spaced relation and constitute with the apertured bottom wall 32 a tubular air passageway adjacent the apertured sides of the chambers 29, 30. The resonating chambers 29, 30 and the entrance orifice associated with each constitute sound-attenuating cavities of the Helmholtz type, each tuned to a selected sound frequency to be attenuated. The air passageway formed by the common wall 32 and the extended side walls 33, 34 is positioned adjacent one of the air flow openings 3 or 4, as shown at Fig. 2 and the entire box-like chambered duct assembly is fixed to the housing wall, as by flanges 35. As indicated at Figs. 1 and 2, a chambered resonating duct assembly of the structure shown at Fig. 2 is affixed to the inner wall of the housing 1 adjacent each of the air flow apertures 3 and 4.

In each of the chambered duct assemblies described, all the resonating cavities are in communication with the tubular air passageway formed by the walls 32, 33 and 34. The wall 32 is common to the passageway and to all the resonating chambers. Chambers tuned to different frequencies are spaced apart along the length of the passageway in the direction of air flow. Each similarly tuned pair of chambers 29 or 30 extends laterally across the air passageway for substantially its full width. It will of course be understood that necessary air flow and resonant cavity dimensioning will determine whether one or several chambers having response to a single frequency are required to span substantially the entire width of the air passageway. Such full transverse extent of each chamber or set of chambers responding to a single frequency is desirable to minimize the amount of sound escaping without attenuation.

It will be further appreciated by those skilled in the art that the chambered duct assemblies may be located either inside or outside the associated air flow opening in the housing 1. In the larger transformer ratings, outside location may be preferable because of restricted interior clearances.

It is a known property of a Helmholtz resonator that it acts as a sink for sound waves at its resonant frequency as they pass by the orifice of the resonator. In its most common form the resonator consists of a tube of length L and cross section S connected to a cavity having a volume V. This combination is directly analogous in its sound-attenuating action to a tuned by-pass filter in an electrical circuit.

In a Helmholtz resonator the resonant frequency f_o is given by the equation

$$f_o = \frac{1}{2\pi}\sqrt{\frac{C^2S}{L_oV}} \text{ cycles per second}$$

where C is the speed of sound and L_o is the effective length of the tube equal to $L+0.8\sqrt{S}$. The computation is normally valid in the linear dimensions of the tube are small as compared to the wave length of sound at the resonant frequency λ_o. This value is given by $\lambda_o = \frac{C}{f_o}$.

Using this relationship the present embodiment utilizes tubular orifices 29a, 30a of rectangular configuration having areas and lengths such that each associated cavity resonates at a desired sound frequency. The resonant frequencies of the several Helmholtz resonators thus formed may be established empirically by varying the cross-sectional area of each orifice until the desired frequency is attentuated. Hence a sound wave of frequency of f_1 will be severely attentuated as it passes the orifice of the Helmholtz resonator tuned to that frequency.

It has been established that alternating current electric apparatus, such as transformers and other induction apparatus, emit sound primarily at frequencies which are even harmonics of the frequency of the applied voltage. The present invention contemplates a chambered duct arrangement wherein a plurality of laterally positioned Helmholtz resonators are provided, each cavity or transverse set of cavities being tuned for resonance at a frequency equal to a double harmonic of the applied alternating voltage. In the embodiments shown at Figs. 1, 2 and 3, two Helmholtz resonators 29 are responsive to sound frequencies of 120 cycles per second, and two resonators 30 are tuned to 240 cycles per second. It is understood that other and higher frequencies may

be similarly provided for and that any desired number of harmonics of a selected fundamental frequency may be attenuated.

As previously pointed out, the air flow openings 3 and 4 in the housing 1 are necessarily quite large when cooling air is to be moved by natural circulation. Such openings have a large periphery and most conveniently are largest in the lateral or width dimension, as shown at Fig. 1. It may thus be necessary to provide a plurality of like Helmholtz resonators tuned to a single frequency in order to span substantially the full width of each opening. Resonators or sets of resonators tuned to other frequencies are arranged along the duct in the direction of air flow, and the one or more resonators at each frequency also span substantially the full width duct. The number of different frequencies (and corresponding sets of resonant chambers) selected for attenuation will depend upon the length of duct available and upon the size of resonator necessary for each frequency to be attenuated.

A chambered duct built in accordance with our invention and installed in a ventilated dry-type transformer in the manner illustrated at Figs. 1 and 2 was tested in an anechoic chamber, and the results of such test are illustrated graphically at Fig. 4. The chambered duct included Helmholtz resonators tuned to frequencies of 120 cps and 240 cps and was built substantially in accordance with the illustration at Fig. 3. Tests were made with all the cavity orifices blocked (i.e. no resonant attenuation), and the attenuation at various frequencies is shown at Fig. 4 by the broken line I. Three other tests were then made using the same resonant cavities but with adjacent air passageway of various heights. The solid-line curves of similar shape each represent the attenuation accomplished by one of these structures with the duct orifices uncovered. It will be observed that in each case the resonating duct structure effected marked attenuation of sound at frequencies of 120 and 240 cycles per second, indicating that egress of sound at these frequencies was effectively reduced.

It is to be understood that the improved Helmholtz resonator structure embodied in our chambered air duct assembly is most effective when used in co-operation with the other sound attenuation and vibration isolating techniques described above. In this way it is possible to eliminate both direct transmission of sound through the necessarily large air flow openings as well as conduction of sound through the structural parts of the base and housing. It will thus be evident that we have described an integrated mounting and housing structure for air-cooled transformers wherein several features operate co-operatively to confine internally generated sound within the housing without impeding the flow of cooling air through the housing.

WHAT WE CLAIM IS:—

1. Air-cooled electric apparatus of the alternating current type enclosed in a ventilated housing which is provided with a cooling air inlet opening and a cooling air outlet opening for the passage of air through the housing to cool said apparatus, wherein adjacent at least one of said openings is mounted a chambered air duct structure comprising a tubular air passageway and at least one resonating chamber, one wall of the or each chamber being constituted by a wall of said passageway, said passageway wall extending across substantially the full width of said air passageway, and the or each chamber communicating with said passageway by means of a tubular orifice passing through said wall, the or each orifice and its associated chamber constituting an acoustic resonator tuned to a selected frequency of the sound generated by said apparatus in operation, whereby to attenuate said sound.

2. An electric apparatus as claimed in claim 1, wherein the or each chambered air duct structure comprises a plurality of lie resonating chambers and orifices constituting a set, all tuned to a common selected frequency, said set extending transversely across substantially the full width of said air passageway.

3. An electric apparatus according to claim 1 or claim 2, wherein the or each chambered air duct structure comprises a plurality of sets or like resonating chambers and associated orifices, each said set extending transversely across the associated air passageway and said sets being positioned at spaced-apart locations along the length of said passageway, the resonators of each set being tuned to a common frequency and each set being tuned to a different frequency of sound to be attenuated.

4. An electric apparatus according to any one of the foregoing claims, wherein said housing is mounted substantially in vibration-isolating independence of the enclosed electric apparatus and sound absorbing means are interposed between the housing walls and the enclosed electric apparatus.

5. An electric apparatus according to any one of the foregoing claims, wherein said housing is provided with upper and lower cooling air flow openings, each with an associated chambered air duct structure, said structures being mounted to extend into the housing and to be positioned respectively above and below the enclosed electric apparatus.

6. An electric apparatus according to any one of the foregoing claims, wherein the or each chambered air duct structure comprises a plurality of resonating chambers and associated orifices positioned in spaced relation along the length of said air passageway and each resonator is tuned to one of several

selected frequencies each of which is an even harmonic of the normal operating frequency of the enclosed apparatus.

7. Electrical apparatus enclosed in a ventilated housing, substantially as described herein and with reference to the accompanying drawings.

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1220717 COMPLETE SPECIFICATION

4 SHEETS

This drawing is a reproduction of the Original on a reduced scale

Sheet 1

Fig. 1.

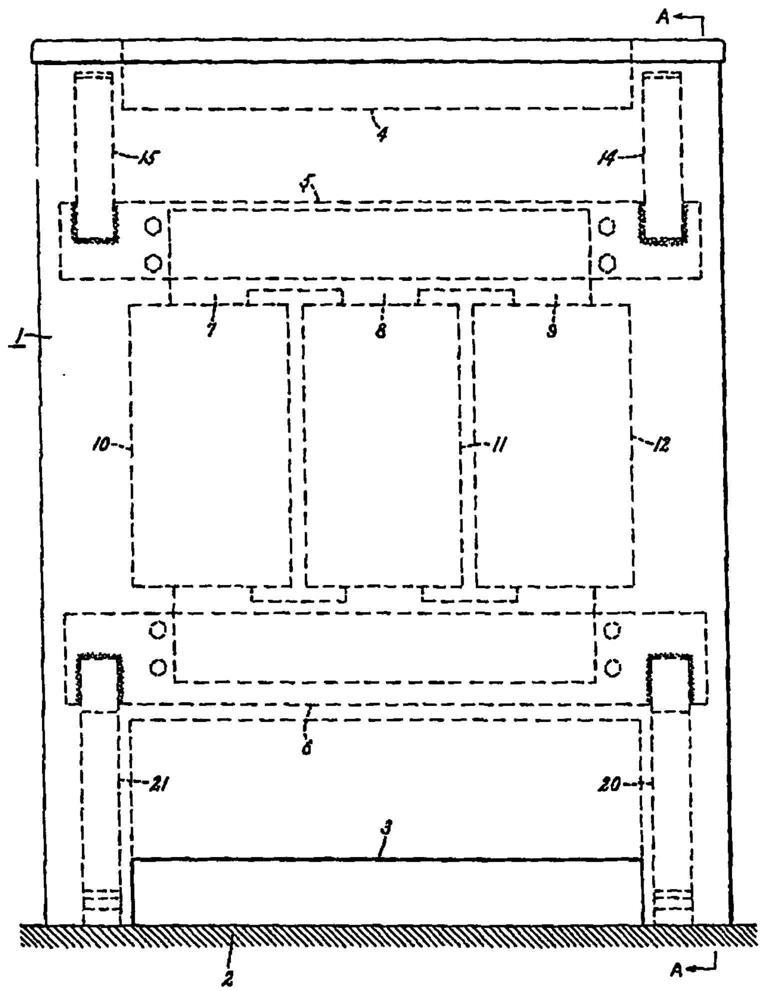

Fig. 2.

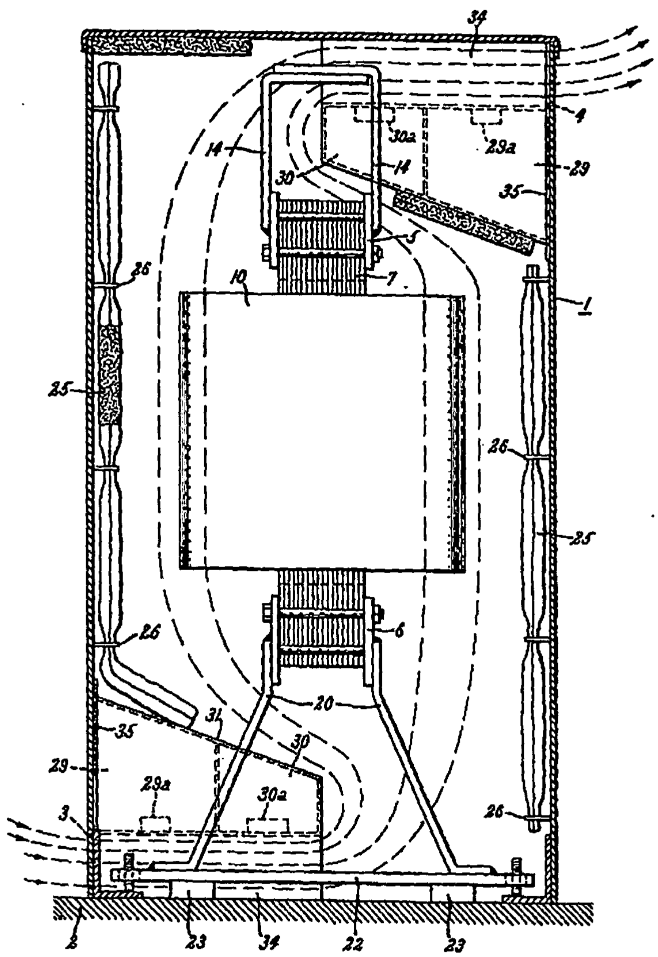
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Fig. 3.

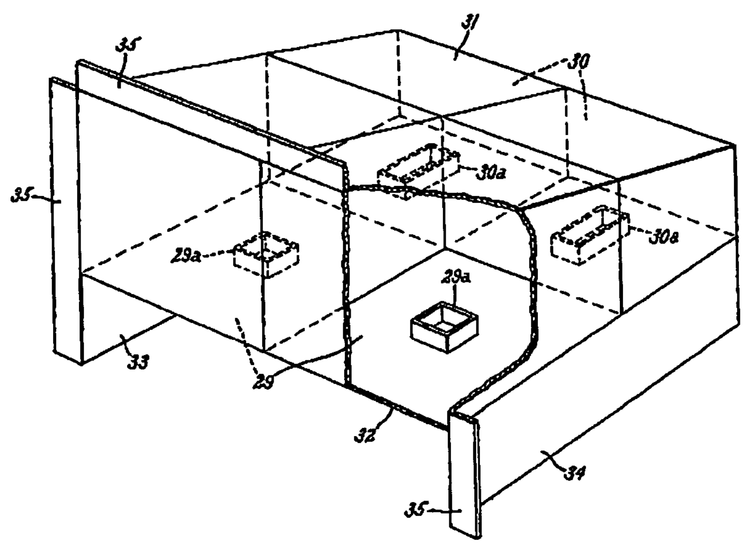
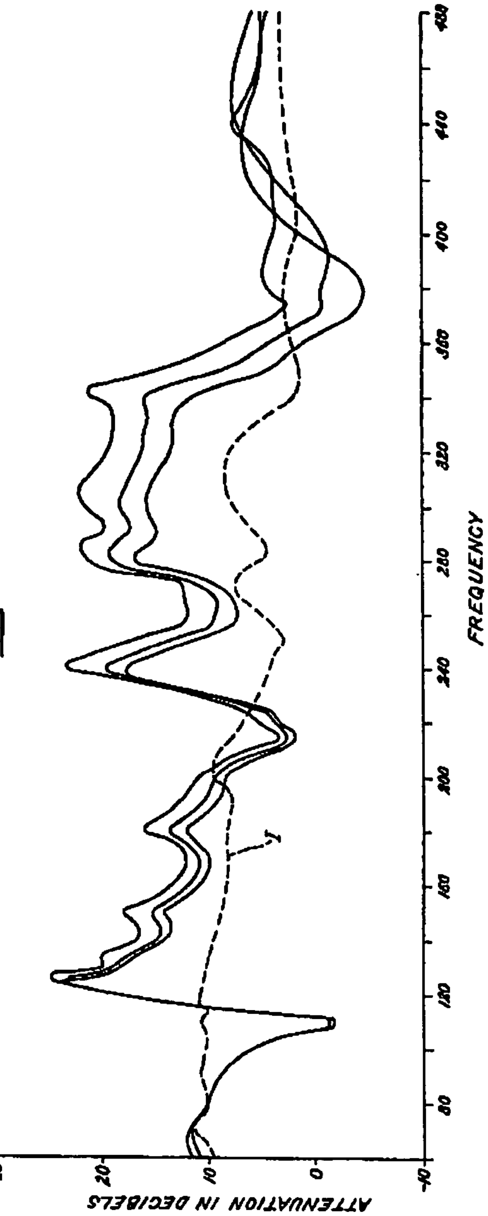


FIG. 4.


ATTENUATION IN DECIBELS
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